PCT/EP2004/011227

Europäisches Patentamt

European Patent Office

Office européen des brevets

REC'D 04 NOV 2004

WIPO PCT

Bescheinigung

Certificate

Attestation

Die angehefteten Unterlagen stimmen mit der ursprünglich eingereichten Fassung der auf dem nächsten Blatt bezeichneten internationalen Patentanmeldung überein.

The attached documents are exact copies of the international patent application described on the following page, as originally filed.

Les documents fixés à cette attestation sont conformes à la version initialement déposée de la demande de brevet international spécifiée à la page suivante.

Den Haag, den
The Hague,
La Haye, le 03. 11. 2004

Der Präsident des Europäischen Patentamts
Im Auftrag
For the President of the European Patent Office
Le Président de l'Office européen des brevets
p.o.

G. Koestel

PRIORITY DOCUMENT

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

Patentanmeldung Nr.
Patent application no.
Demande de brevet n° PCT/EP 04/002912

Blatt 2 der Bescheinigung
Sheet 2 of the certificate
Page 2 de l'attestation

Anmeldung Nr.:
Application no.:
Demande n°: PCT/EP 04/002912

Anmelder:
Applicant(s):
Demandeur(s): 1. VIDA, Dr. Nikolaus - Scheer, Germany

Bezeichnung der Erfindung:
Title of the invention:
Titre de l'invention: Three-dimensional surface structure for reduced friction resistance and improved head exchange

Anmeldetag:
Date of filing:
Date de dépôt: 19 March 2004 (19.03.2004)

In Anspruch genommene Priorität(en)
Priority(ies) claimed
Priorité(s) revendiquée(s)

Staat: / State: / Pays:	Tag: / Date: / Date:	Aktenzeichen: / File no. / Numéro de dépôt:
Germany	19 March 2003 (19.03.2003)	203 04 444.4

Bemerkungen:
Remarks:
Remarques:

Further Priority claims:

Europe	03 June 2003 (03.06.2003)	03 012 638.7

THREE-DIMENSIONAL SURFACE STRUCTURE FOR REDUCED FRICTION RESISTANCE AND IMPROVED HEAT EXCHANGE

Description

The invention concerns in general surfaces along which media, e.g. gases, liquids or two-phase mixtures are flowing and especially surfaces as described in EP 92 911 873.5, PCT RU92/00106 or EP 96 927 047.9, PCT/EP96/03200 also termed TLT-reliefs or TLT-surfaces.

It is known that the process when a continuous medium like a gas, a liquid or a two-phase mixture flows along a surface covered with very special three-dimensional concave reliefs, named the TLT-reliefs and being described in more detail in EP 92 911 873.5, PCT RU92/00106 and in EP 96 927 047.9, PCT/EP96/03200, which are completely incorporated here by reference, is accompanied by self-organization of secondary twisted tornado-like jets originating in each concavity of the relief and flowing out of it into the parent flow.

It is known that friction could be reduced by means of dimples located at said surface and that in addition heat transfer between said surface and the streaming media, e.g.

gases, liquids and two-phase mixtures containing gases and liquids could be increased.
However, there are special situations in which there is minor interest in drag reduction and major interest in an increased heat transfer, as for instance for heat exchange devices as heat sinks in general, bonnets, chillers and many more. In addition, a huge number of devices demand for drag reduction as vehicles, aircrafts and ships in general. Moreover, any fluid transportation would benefit from a reduced drag resistance as this would decrease energy consumption or increase transportation speed.

Therefore it is an object of the invention to show a new way how the properties of a surface, especially concerning friction resistance and heat exchange with a surrounding medium, can be improved.

The object of the invention is achieved in a surprisingly simple manner by a subject matter of one of the attached independent claims. Advantageous embodiments and refinements are defined in the respective dependent claims.

The inventors surprisingly found that a certain geometry of the TLT-reliefs results in a significant improvement of the flow properties.

Accordingly the invention proposes a surface, which comprises dimples, wherein the edges of said dimples are rounded, thereby forming a central dimple area and at least one curvature area for each dimple, which continuously connects the dimple to the surrounding surface.

Such a geometry of a surface especially improves the flow properties with respect to friction resistance as also with respect to heat and mass transfer for surfaces, along which a medium flows, which consists of a gas, a liquid, a two-phase mixture, or a mixture of multiple phases.

The underlying principle are secondary vortices, which originate in the dimples and lead to an organized transportation of medium from the surface to the main flow. Due to the reduced pressure inside the vortex flows the boundary layer is sucked in, so that the thickness of the boundary layer does not increase.

Said central dimple preferably area essentially has the form of a section of a sphere or an ellipsoid.

With great advantage said curvature area of the surface comprises at least a first curvature area and a second curvature area, the first curvature area having a different curvature than the second curvature area. Preferably said first curvature area is rounded with a first rounding radius and said second curvature area is rounded with a second rounding radius.

As will also be seen later on, especially suitable for drag reduction, i.e. reduction of friction resistance, and related flow properties like reduced drag vortices and reduced lee waves, is a surface comprising dimples having a relatively low depth in relation to the diameter. In this regime it can be of special advantage to combine two different, consecutive curvature areas to realize different sizes of the central dimple area.

Also two curvature areas are very advantageous in order to achieve a gentle transition from the dimple to the surrounding surface, thereby reducing the probability of destruction of the advantageous secondary vortices, which originate in the dimples.

With advantage the dimples are arranged periodically on the surface. In order to realize a good coverage of the surface, the centers of three adjoining dimples preferably form a triangle, the distance between two neighboring dimples having a constant value t_1 and the distance between two rows of dimples having a constant value t_2.

The maximum coverage can be reached in this kind of arrangement when the curvature areas of said three adjoining dimples are in contact with each other.

Even in this arrangement a small area of flat surface remains in the center of three respective adjoining dimples. In this location preferably additional smaller-sized dimples are provided, by which the flow properties can be further improved.

The inventors also surprisingly found that there are regimes of significantly increased heat exchange and regimes of strongly reduced drag resistance.

Accordingly a surface, along which a medium flows, said medium consisting of a gas, a liquid, a two-phase mixture, or a mixture of multiple phases, with dimples having a diameter d and a depth h with a ratio between said depth and said diameter of $h/d \leq 0.1$, also lies within the scope

of the invention. In this geometrical regime the surface shows an especially low friction resistance.

With a ratio of $h/d \geq 0.1$ the surface shows an especially high heat transfer between-said surface and said flowing medium.

The dimpled surfaces or reliefs with small relative depth of $h/d \leq 0.1$, where h is the concavity depth and d is the concavity diameter, significantly reduce the friction resistance of the shaped surfaces, as well as intensify the heat and mass transfer, to a lesser extend, however, as compared with the friction resistance of a smooth surface.

The dimpled surfaces or reliefs with a larger relative depth of $h/d \geq 0,1$ significantly intensify the heat and mass transfer with the aerohydrodynamic losses being constant or lagging behind the rate of intensification, with considerable disturbance of Reynolds in favorite to heat transfer.

Also within the scope of the invention lies a means for locomotion with at least one surface, along which a medium flows when said means for locomotion is in movement, wherein the at least one surface is provided with dimples as described above, in particular provided as a car, a truck, a train, an airplane, a helicopter or a ship.

In comparison to an otherwise identical means for locomotion or vehicle with a flat surface certain flow properties are improved, especially the drag resistance is reduced, the forming of drag vortices is reduced, the

forming of lee waves is reduced, and the separation point of the flow is moved further downstream.

Further a device for transportation of a medium lies within the scope of the invention, which comprises at least one surface with dimples as described above. With advantage the surface with dimples is provided as an inner surface of a transport channel, in particular a pipe, of the device, in which the medium is transported. The implementation in such a device is of advantage due to a further result of the described surface structure found by the inventors, consisting in a reduced deposition of particles on the surface compared to a flat surface.

Further a device for heat exchange between a flowing medium and at least one surface of the device, in particular an air-conditioning system or part thereof, is proposed, wherein the at least one surface is provided with dimples. Here it can be taken advantage of the effect of reduced ice-forming on a surface, which comprises the described dimples, in comparison to a flat surface.

The invention further proposes a container for cooking and/or for keeping warm, wherein the outside surface of the bottom wall of the container and/or the outside surface of the side walls of the container comprise a surface with the described dimples.

Also a layer or coating for applying on a surface is proposed, which comprises a surface with the described dimples. By use of such a layer, a device or vehicle having a surface along which a medium flows can be upgraded for improved flow properties, such as reduced friction

resistance or improved heat or mass transfer or a combination thereof.

For this purpose the layer can advantageously be provided with a first side and a second side, wherein said first side comprises dimples as described above and said second side comprises a self-adhesive coating.

Accordingly the invention proposes a method for producing a surface with reduced friction resistance and/or improved heat exchange with a surrounding medium, comprising the step of applying a described layer onto said surface.

Also a method is proposed for producing a surface with reduced friction resistance and/or improved heat exchange with a surrounding medium, which comprises the steps of
- providing a workpiece with at least one surface and
- imprinting into said at least one surface a structure comprising dimples.

Another inventive method for producing a surface with reduced friction resistance and/or improved heat exchange with a surrounding medium, comprises the steps of
- providing a casting mold with at least one structured surface and
- molding, in particular injection molding, of a workpiece with at least one surface comprising dimples by means of said casting mold.

The invention is not limited to the described production methods, but shall also encompass any other method, which is suitable to produce a surface comprising the above described dimples.

Also within the scope of the invention lies the usage of a surface with dimples as described above as a surface of

- a means for locomotion or
- a device for transportation of a medium or
- a device for heat exchange or
- a container for cooking and/or for keeping warm.

In the following the invention is described exemplary in more detail on the basis of preferred embodiments and with reference to the enclosed drawings. Therein same reference marks in the drawings indicate same or similar parts.

Brief Description of the Figures

It is shown in:

Fig. 1: a schematic diagram of a first distribution of dimples,

Fig. 2: a schematic diagram of a cross section through a dimple according to a first preferred embodiment,

Fig. 1: a schematic diagram of a second distribution of dimples,

Fig. 4: a schematic diagram of a cross section through a dimple according to a second preferred embodiment,

Fig. 5: a schematic diagram of a train with an inventive surface,

Fig. 6: schematically a comparison of two wing profiles,

Fig. 7: a schematic diagram of a container immersed in a flowing fluid,

Fig. 8: schematically a transport channel, the inner surface of which being provided with dimples,

Fig. 9: a schematic diagram of a measurement arrangement for measuring the velocity profiles over different investigated plates comprising a laser Doppler anemometer (LDA),

Fig. 10: a schematic diagram of a metal plate with TLT relieves or dimples,

Fig. 11: a schematic diagram of a plate with variable TLT relieves or dimples,

Fig. 12: a schematic diagram of a plate with TLT relieves showing the points, at which the velocity was measured.

Detailed Description of the Invention

Fig. 1 shows schematically a preferred distribution of dimples 10 on a surface. The dimples 10 are arranged periodically, wherein the centers of three directly adjoining dimples 10 form an equilateral triangle. The angle α therefore has a value of 60°. The distance between the centers of two adjoining dimples 10, which is equal to the length of a side of the triangle, has a constant value t_1. The distance between two rows of dimples 10, which equals the height of the triangle, has a constant value t_2. The parameters t_1 and t_2 can have different values depending on the purpose for which the surface shall be utilized.

Fig.2 shows a cross section through the center of one of the dimples 10 shown in Fig. 1, perpendicular to the surface. In this embodiment the dimple essentially has the form of a calotte with radius R_{sph}, height h_c and diameter d_c. Further the dimple 10 is rounded at the edges with a rounding radius R_s. Thereby in this example the dimple is

symmetrical with respect to rotation around an axis through the center of the dimple and perpendicular to the surface.

Fig. 3 shows schematically a top view of a distribution of dimples comprising a central dimple area 110, a first curvature area 120 and a second curvature area 130, the named areas being arranged consecutively from the center of the dimple to the outside.

The central dimple area has a diameter of d_1, the first curvature area has an diameter of d_2 and the second curvature area has a diameter of t_1. The dimples are arranged similar to Fig. 1, but in this preferred embodiment the outer rims of two adjoining dimples are in contact with each other for a maximum surface coverage.

Again, the centers of three adjoining dimples form an equilateral triangle, the distance between the centers of two adjoining dimples having the constant value t_1 and the distance between two rows of dimples having the constant value t_2. In this embodiment therefore the diameter of the second curvature area equals the distance between two adjoining dimples t_1.

A small area of surface remains in the center between three adjoining dimples. In this location preferably additional smaller-sized dimples 200 can be provided, thereby further improving the flow properties of the surface.

The cross section AA' through the center of a dimple perpendicular to the surface is shown in more detail in Fig. 4.

The central dimple area 110 essentially has the form of a section of a sphere, followed in the outward direction by two consecutive curvature areas. Since the curvature areas can be described as an arc, which is rotated in space, they have a surface formed as a part of a torus or similar thereto.

The form of the central dimple area, of the first curvature area and of the second curvature area in the shown cross section perpendicular to the surface and through the center of the dimple is defined by the following parameters:

d_1:	Diameter of the central dimple area,
d_2:	Outer diameter of the first curvature area,
t_1:	Outer diameter of the second curvature area,
R_1, C_1:	Radius and center point of the sphere, the section of which forms the surface of the central dimple area,
R_2, C_2:	Radius and center point of the rounding radius of the first curvature area,
R_3, C_3:	Radius and center point of the rounding radius of the second curvature area,
P_1:	Transition point from the central dimple area to the first curvature area,
P_2:	Transition point from the first curvature area to the second curvature area,
P_3:	Transition point from the second curvature area to the surrounding surface,
h_1:	Difference in height between the lowest point of the central dimple area and the outer rim of the central dimple area,

h_2: Difference in height between the inner rim of the first curvature area and the outer rim of the first curvature area,

h_3: Difference in height between the inner rim of the second curvature area and the outer rim of the second curvature area,

α_1: Angle between the y-axis and a line connecting C_2 and C_3,

α_2: Angle between the x-axis and a line connecting C_1 and C_2,

f: Parameter related to the portion of the surface covered by the central dimple area in relation to the combined area of central dimple area and curvature areas.

There is one point, in which the circle with radius R_1, being part of the sphere that forms the central dimple area, and the circle with radius R_2, defining the curvature of the first curvature area, have a mutual tangent. Further, there is another point, in which the circle with radius R_2 and the circle with radius R_3 have a mutual tangent.

To completely describe the form of the dimple a set of parameters, in particular the parameters d_1, α_1, α_2, R_2/R_1 and f, are chosen according to the necessities of the specific purpose the surface shall be used for and depending on whether drag reduction or improved heat exchange has priority. For most purposes the coverage of the surface by the central dimple areas lies below 70%, but also a greater coverage falls within the scope of the present invention.

The remaining of the named parameters can be calculated by means of the following equations:

$$R_1 = \frac{d_1}{2 \cdot \sin\alpha_1},$$

$$R_2 = \frac{R_2}{R_1} \cdot \frac{d_1}{2 \cdot \sin\alpha_1},$$

$$R_2 = \frac{t_1 - \frac{d_1}{2} \cdot \frac{R_2}{R_1} \cdot \frac{(1-\sin\alpha_1)}{\sin\alpha_2}}{\sin\alpha_2},$$

$$h_1 = \frac{d_1}{2} \cdot \frac{(1-\cos\alpha_1)}{\sin\alpha_1},$$

$$h_2 = R_2 \cdot (\cos\alpha_2 - \cos\alpha_1),$$

$$h_3 = R_3 \cdot (1-\cos\alpha_2),$$

$$H = h_1 + h_2 + h_3,$$

$$t_1 = \sqrt{\frac{\pi}{6 \cdot f}} \cdot d_1,$$

$C_1 = (X_{C1}, Y_{C1})$ with $X_{C1} = 0$, $Y_{C1} = R_1 - H$,

$C_2 = (X_{C2}, Y_{C2})$ with $X_{C2} = \frac{d_1}{2} \cdot \left(1 + \frac{R_2}{R_1}\right)$, $Y_{C2} = R_3 + \frac{X_{C3} - X_{C2}}{tg\alpha_2}$,

$C_3 = (X_{C3}, Y_{C3})$ with $X_{C3} = \frac{t_1}{2}$, $Y_{C3} = -R_3$,

$P_1 = (X_{P1}, Y_{P1})$ with $X_{P1} = \frac{d_1}{2}$, $Y_{P1} = H - h_1$,

$P_2 = (X_{P2}, Y_{P2})$ with $X_{P2} = \frac{t_1}{2} - R_3 \cdot \sin\alpha_2$, $Y_{P2} = R_3 \cdot (\cos\alpha_2 - 1)$,

$P_3 = (X_{P3}, Y_{P3})$ with $X_{P3} = \frac{t_1}{2}$, $Y_{P3} = 0$,

said equations being defined in a two-dimensional coordinate-system with the x-axis in the plane of the

surface and with the y-axis through the center of the dimple and perpendicular to the surface.

In Fig. 5 to 8 various preferred embodiments of the invention are shown, thereby demonstrating the broad range of applications, for which an inventive surface with dimples as described above can be utilized. The shown embodiments are only exemplary and do not limit the scope of the invention, as numerous other applications could be named.

In Fig. 5 a high-speed train 300 is shown schematically, which is provided with an inventive outer surface 310, which comprises a multitude of dimples, the form, size and distribution of which is adapted according to speed and geometry of the train 300.

A train as shown in Fig. 5 is characterized by improved flow properties in comparison to a similar train with a flat surface. In particular the forming of drag vortices is reduced as also the forming of lee wave in case of side winds. Consequently the overall friction resistance is also reduced.

A further effect of the inventive surface lies in the separation point of the flow being moved further downstream or in certain circumstances the complete disappearance of a separation point. This effect allows for instance for providing completely new wing profiles. In Fig. 6 a conventional wing profile 400 is shown in comparison with a modified wing profile 410, the use of which becomes possible for example as a wing of an airplane, when the surface is provided with an inventive dimple structure.

Fig. 7 shows a further utilization of an inventive surface for a container usable for cooking or for keeping some substance at a desired temperature. The container schematically shown in Fig. 7 is immersed in a flowing fluid 510. The outside surface of the bottom wall 520 of the container and/or the outside surface of the side walls 530 of the container comprise a surface with periodically arranged dimples.

In this embodiment the dimples are of the type shown in Fig. 1 and Fig. 2, preferably with the following values:

$t_1 = 28.6$ mm,
$t_2 = 33.0$ mm,
$d_c = 20.0$ mm,
$h_c = 3.0$ mm,
$R_{ahp} = 68.2$ mm,
$R_S = 5.0$ mm,

or scaled up or down keeping essentially the ratios

$$\frac{t_1}{t_2} = \frac{28.6}{33.0}, \quad \frac{R_{ahp}}{R_S} = \frac{68.2}{3.0}, \quad \frac{R_S}{h_c} = \frac{5.0}{3.0}$$

The above named values result in a fraction of the surface, which is covered by the dimples, of about 0.3.

Fig. 8 schematically shows a pipe 600, the inner surface 610 of which is provided with dimples 630. This pipe can be utilized as a transport channel for transportation of a medium. The significant improvement achieved by using the inventive surface in this embodiment lies in a reduced

deposition of particles on the surface due to the suction of the boundary layer from the surface into the main flow by means of the self-organizing vortex flows originating in the dimples.

Furthermore, because of the same reasons the forming of ice on the surface is reduced, so that such a pipe can also be utilized with great advantage in a device, in which a medium is to be cooled, like an air-conditioning system, especially an air-conditioning system used in an airplane.

The inventors have studied the phenomenon of friction resistance reduction on the TLT-relief surfaces using a laser Doppler anemometer (LDA) to measure velocity profiles formed over the surfaces being flowed around, and the theorem of momentum to process the obtained results. The experimental setup is schematically illustrated in Fig. 9.

The investigated plate 704 is positioned in the test section 710 of the cavitation tunnel. By means of a laser 706 arranged on an optical bench 708 and a signal control and preliminary processing unit 702 as parts of the laser Doppler anemometer (LDA) the flow properties are measured.

The test specimens, which were examined by the inventors, were thin flat plates of the following two types:

- metal plates 800 of size 378 × 679 mm^2 either having a smooth surface or a TLT-relief formed surface provided with dimples 802 as shown in Fig. 10,
- plates 810 of the same size with an elastic rubber coating 820 applied onto a flat plate with either a continuous surface or a surface provided with the

regular grid of axially symmetrical holes connecting the elastic coating 820 above them with the pressure-tight chamber beneath the plate 810 as shown in Fig. 11.

By varying the pressure in the pressure-tight chamber, the experimentalist can form on the flowed-around surface the TLT relief with various depth of the concavities by retracting the elastic coating 820 inside the hole in the plate. When the pressure above and beneath the plate is the same, the surface being flowed around represents a grid of rubber membranes covering the holes in the plate and interacting with the ambient flow. Reducing the pressure beneath the plate, one can control the TLT relief with the depth of the relief concavities varying almost from zero to the depths corresponding to the radius of the hole in the support plate.

Fig. 11 further shows bearing cylinders 830, the vacuum cover 850, which seals the air-tight chamber and a vacuum union 840.

A similar arrangement as the one shown in Fig. 11 can also be used in a device or a vehicle to change the size, the form and/or the number of the dimples on the surface during operation of said device or vehicle. That way the flow properties of the device or vehicle can be flexibly adapted to changing operating conditions.

During the experiment performed by the inventors the hydrodynamic characteristics of the following objects were compared:

- the TLT-relief metal plate with the smooth surface metal plate;
- the adjustable elastic TLT-relief plate with the smooth plate with no holes on the support plate having the same elastic coating;
- the plates with various TLT reliefs on the metal surface with the plates with membranes and different TLT reliefs on the elastic surface.

The measurements were carried out in a cavitational tunnel, which was the cavitational tunnel of the Hamburgische Schiffbau-Versuchsanstalt GmbH (HSVA), in which the flow was characterized by the Reynolds numbers defined as follows:

- along the plate length considering the preliminary section within the range:

$$9\times10^5 \leq Re \leq 7,5\times10^6 ;$$

- along the TLT relief concavity diameter within the range:

$$2.5\times10^4 \leq Re \leq 6\times10^5.$$

The onflowing stream turbulence rate was high and according to the laser measurements comprised:

$$0.1 \leq \sigma \approx \sqrt{(u'^2)}/u_\infty \leq 0.3$$

The water temperature in the flow was measured within the range:

$$15°C \leq T \leq 22°C.$$

The velocity profiles were measured at thirty points 930 arranged on the surface of the plate 910 shown in Fig. 12. The profile speed measurements on the ambient surfaces of the flat plates and the plates with TLT relief comprising

dimples 920 were performed at these points 930, which are indicated by crosses.

The measurements were processed using the theorem of momentum in accordance with the procedure suggested by I.Nikuradze in „Turbulente Reibungsschichten an der Platte", ZWB, R.Oldenbourg, Muenchen und Berlin, 1942, and comprised determination of the values of the local and full friction resistance coefficients C_F' and C_F. The experimental data are represented in the table shown below.

It follows from the table that the friction resistance of the metallic surface with the TLT relief is ~ 22% lower than that of the smooth metallic surfaces. The friction resistance of the surface with elastic rough rubber coating and the TLT relief on it is ~ 34% lower than that of the smooth elastic rough rubber coated surface.

Table

Speed of undisturbed flow	Reynolds number to length of the plate	Temperature of plates ambiant fluid	Position data of the points, where the speed profiles over the plate are measured		Displacement layer thickness of line of flow over the plate		Thickness of the loss of impulse in the flow over the plate		Formparametr $H_{12}=\delta_1(x)/\delta_2(x)$	Local friction ratio	Total friction ratio	Plate name, type
			I. Section	II.section	I. section	II.section	I. section	II.section				
U_∞ m/s	$Re=U_\infty \cdot l/\nu$ 10^{-6}	T°C	X_1 m	X_2 m	$\delta_1(x_1)$ 10^3 m	$\delta_1(x_1)$ 10^3 m	$\delta_2(x_1)$ 10^3 m	$\delta_2(x_2)$ 10^3 m		C'_f 10^3	C'_f 10^3	
Measurement on metal plates with smooth and formed streamlined surfaces												
3 5 7	2,415 4,025 5,640	≈20	0,239	0,626	0,80 0,72 0,67	1,71 1,53 1,43	0,62 0,56 0,52	1,34 1,19 1,12	≈1,28	3,70 3,27 3,10	4,20 3,73 3,54	M_{sm}
3 5 7	2,415 4,025 5,640	≈20	0,239	0,626	0,67 0,60 0,56	1,42 1,27 1,18	0,52 0,47 0,44	1,11 0,99 0,92	≈1,28	3,03 2,70 2,50	3,47 3,10 2,85	M_{TLT}^{45}
Measure results of the elastic, smooth and formed surface with rough rubber cover												
3 5 7	2,415 4,025 5,640	≈20	0,239	0,626	1,01 0,90 0,83	2,14 1,90 1,75	0,80 0,71 0,66	1,69 1,50 1,38	≈1,27	4,63 4,08 3,74	5,30 4,67 4,28	E_{sm}
3 5 7	2,415 4,025 5,640	≈20	0,239	0,626	0,78 0,69 0,63	1,63 1,45 1,34	0,61 0,54 0,50	1,28 1,14 1,05	≈1,27	3,76 3,10 2,87	3,95 3,53 3,27	E_{TLT}^{45}

Claims

1. Surface along which a medium flows, said medium consisting of a gas, a liquid, a two-phase mixture, or a mixture of multiple phases, characterized in that said surface comprises dimples, wherein the edges of said dimples are rounded, thereby forming a central dimple area and at least one curvature area for each dimple, which continuously connects the dimple to the surrounding surface.

2. Surface according to claim 1, wherein said central dimple area essentially has the form of a section of a sphere or an ellipsoid.

3. Surface according to claim 1 or 2, wherein said curvature area comprises at least a first curvature area and a second curvature area, the first curvature area having a different curvature than the second curvature area.

4. Surface according to claim 3, wherein said first curvature area is rounded with a first rounding radius and said second curvature area is rounded with a second rounding radius.

5. Surface of claim 4, wherein the central dimple area essentially has the form of a section of a sphere, and the form of the central dimple area, of the first curvature area and of the second curvature area in a cross section perpendicular to the surface and through the center of the dimple is defined by the following parameters:

d_1: Diameter of the central dimple area,

d_2: Outer diameter of the first curvature area,

t_1: Outer diameter of the second curvature area,

R_1, C_1: Radius and center point of the sphere, the section of which forms the surface of the central dimple area,

R_2, C_2: Radius and center point of the rounding radius of the first curvature area,

R_3, C_3: Radius and center point of the rounding radius of the second curvature area,

P_1: Transition point from the central dimple area to the first curvature area,

P_2: Transition point from the first curvature area to the second curvature area,

P_3: Transition point from the second curvature area to the surrounding surface,

h_1: Difference in height between the lowest point of the central dimple area and the outer rim of the central dimple area,

h_2: Difference in height between the inner rim of the first curvature area and the outer rim of the first curvature area,

h_3: Difference in height between the inner rim of the second curvature area and the outer rim of the second curvature area,

α_1: Angle between the y-axis and a line connecting C_2 and C_3,

α_2: Angle between the x-axis and a line connecting C_1 and C_2,

f: Parameter related to the portion of the surface covered by the central dimple area in relation to the combined area of central dimple area and curvature areas,

wherein a set of parameters, in particular the parameters d_1, α_1, α_2, R_2/R_1 and f, are chosen and the remaining parameters are calculated by means of the following equations with a tolerance of ± 10% for each parameter:

$$R_1 = \frac{d_1}{2 \cdot \sin\alpha_1},$$

$$R_2 = \frac{R_2}{R_1} \cdot \frac{d_1}{2 \cdot \sin\alpha_1},$$

$$R_2 = \frac{t_1 - \frac{d_1}{2} \cdot \frac{R_2}{R_1} \cdot \frac{(1-\sin\alpha_1)}{\sin\alpha_2}}{\sin\alpha_2},$$

$$h_1 = \frac{d_1}{2} \cdot \frac{(1-\cos\alpha_1)}{\sin\alpha_1},$$

$$h_2 = R_2 \cdot (\cos\alpha_2 - \cos\alpha_1),$$

$$h_3 = R_3 \cdot (1-\cos\alpha_2),$$

$$H = h_1 + h_2 + h_3,$$

$$t_1 = \sqrt{\frac{\pi}{6 \cdot f}} \cdot d_1,$$

$$C_1 = (X_{C1}, Y_{C1}) \text{ with } X_{C1} = 0, \quad Y_{C1} = R_1 - H,$$

$$C_2 = (X_{C2}, Y_{C2}) \text{ with } X_{C2} = \frac{d_1}{2} \cdot \left(1 + \frac{R_2}{R_1}\right), \quad Y_{C2} = R_3 + \frac{X_{C3} - X_{C2}}{tg\alpha_2},$$

$$C_3 = (X_{C3}, Y_{C3}) \text{ with } X_{C3} = \frac{t_1}{2}, \quad Y_{C3} = -R_3,$$

$$P_1 = (X_{P1}, Y_{P1}) \text{ with } X_{P1} = \frac{d_1}{2}, \quad Y_{P1} = H - h_1,$$

$$P_2 = (X_{P2}, Y_{P2}) \text{ with } X_{P2} = \frac{t_1}{2} - R_3 \cdot \sin\alpha_2, \quad Y_{P2} = R_3 \cdot (\cos\alpha_2 - 1),$$

$$P_3 = (X_{P3}, Y_{P3}) \text{ with } X_{P3} = \frac{t_1}{2}, \quad Y_{P3} = 0,$$

said equations being defined in a two-dimensional coordinate-system with the x-axis in the plane of the surface and with the y-axis through the center of the dimple and perpendicular to the surface.

6. Surface according to any of the preceding claims, wherein said dimples are arranged periodically on said surface.

7. Surface according to any of the preceding claims, wherein the centers of three adjoining dimples form a triangle, the distance between two neighboring dimples having a constant value t_1 and the distance between two rows of dimples having a constant value t_2.

8. Surface according to claim 7, wherein the curvature areas of said three adjoining dimples are in contact with each other.

9. Surface according to claim 7 or 8, wherein additional dimples of a different size are provided, which are located in the center of three respective adjoining dimples.

10. Surface along which a medium flows, said medium consisting of a gas, a liquid, a two-phase mixture, or a mixture of multiple phases, preferably according to one of claims 1 to 8, characterized in that
said surface comprises dimples having a diameter of d and a depth of h with a ratio between said depth and said diameter of $h/d \leq 0.1$.

11. Surface along which a medium flows, said medium consisting of a gas, a liquid, a two-phase mixture, or a

mixture of multiple phases,, preferably according to one of claims 1 to 8, characterized in that said surface comprises dimples having a diameter of d and a depth of h with a ratio between said depth and said diameter of $h/d \geq 0.1$. —

12. Surface according to claim 10, characterized by a reduced friction resistance.

13. Surface according to claim 11, characterized by an increased heat transfer between said surface and said flowing medium.

14. Means for locomotion with at least one surface, along which a medium flows when said means for locomotion is in movement, wherein the at least one surface is provided with dimples according to one of claims 1 to 13, in particular provided as a car, a truck, a train, an airplane, a helicopter or a ship.

15. Means according to claim 14, characterized in that
- the drag resistance is reduced and/or
- the forming of drag vortices is reduced and/or
- the forming of lee waves is reduced and/or
- the separation point of the flow is moved further downstream

in comparison to an otherwise identical means with a flat surface.

16. Device for transportation of a medium, comprising at least one surface with dimples according to one of claims 1 to 13.

17. Device according to claim 16, comprising a transport channel, wherein the at least one surface with dimples is provided as the inner surface of said transport channel.

18. Device according to claim 17, wherein said transport channel is a pipe.

19. Device according to one of claims 16 to 18, characterized in that the deposition of particles on said at least one surface is reduced in comparison to an otherwise identical device with a flat surface.

20. Device for heat exchange between a flowing medium and at least one surface of the device, wherein the at least one surface is provided with dimples according to one of claims 1 to 13, in particular provided as a part of an air-conditioning system.

21. Device according to claim 20, characterized in that the forming of ice on said at least one surface is reduced in comparison to an otherwise identical device with a flat surface.

22. Container for cooking and/or for keeping warm, characterized in that the outside surface of the bottom wall of the container and/or the outside surface of the side walls of the container comprise a surface with dimples according to one of claims 1 to 13.

23. Layer for applying on a surface, wherein said layer comprises a surface with dimples according to one of claims 1 to 13.

24. Layer according to claim 23, having a first side and a second side, characterized in that said first side comprises dimples according to one of claims 1 to 13 and said second side is self-adhesive.

25. Method for producing a surface with reduced friction resistance and/or improved heat exchange with a surrounding medium, comprising the step of
- applying a layer according to claim 23 or 24 onto said surface.

26. Method for producing a surface with reduced friction resistance and/or improved heat exchange with a surrounding medium, comprising the steps of
- providing a workpiece with at least one surface and
- imprinting into said at least one surface a structure comprising dimples, in particular generating a surface according to one of claims 1 to 13.

27. Method for producing a surface with reduced friction resistance and/or improved heat exchange with a surrounding medium, comprising the steps of
- providing a casting mold with at least one structured surface and
- molding, in particular injection molding, of a workpiece with at least one surface comprising dimples, in particular a surface according to one of claims 1 to 13, by means of said casting mold.

28. Usage of a surface according to one of claims 1 to 13 as a surface of

- a means for locomotion or
- a device for transportation of a medium or
- a device for heat exchange or
- a container for cooking and/or for keeping warm.

Abstract

In order to improve the flow properties of a surface the invention proposes a surface along which a medium flows, said medium consisting of a gas, a liquid, a two-phase mixture, or a mixture of multiple phases, wherein said surface comprises dimples, the edges of which are rounded, thereby forming a central dimple area and at least one curvature area for each dimple, which continuously connects the dimple to the surface.

The invention further proposes various devices comprising the surface, a layer comprising the surface, and also methods for producing the surface.

Fig. 1

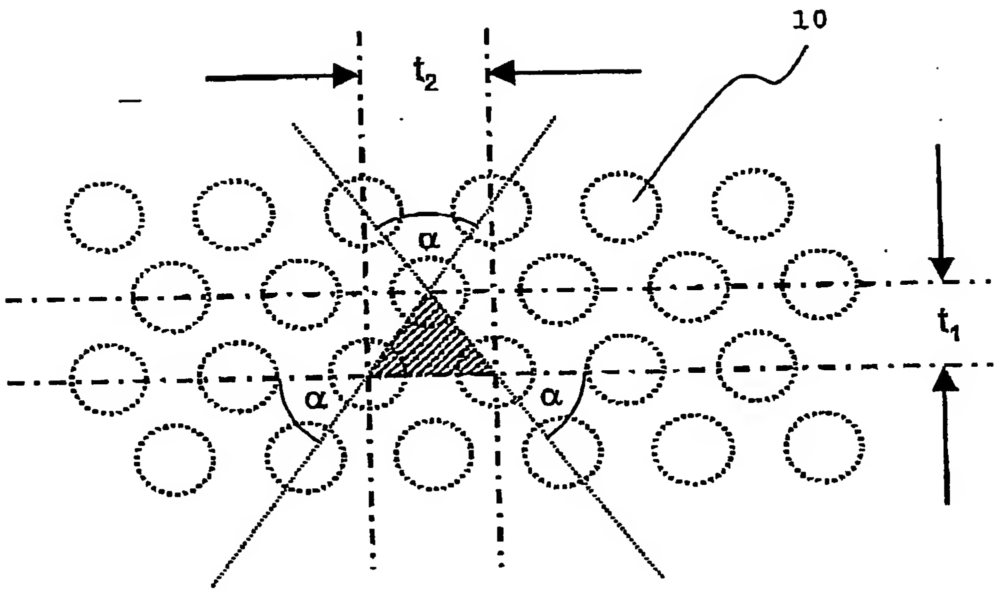


Fig. 2

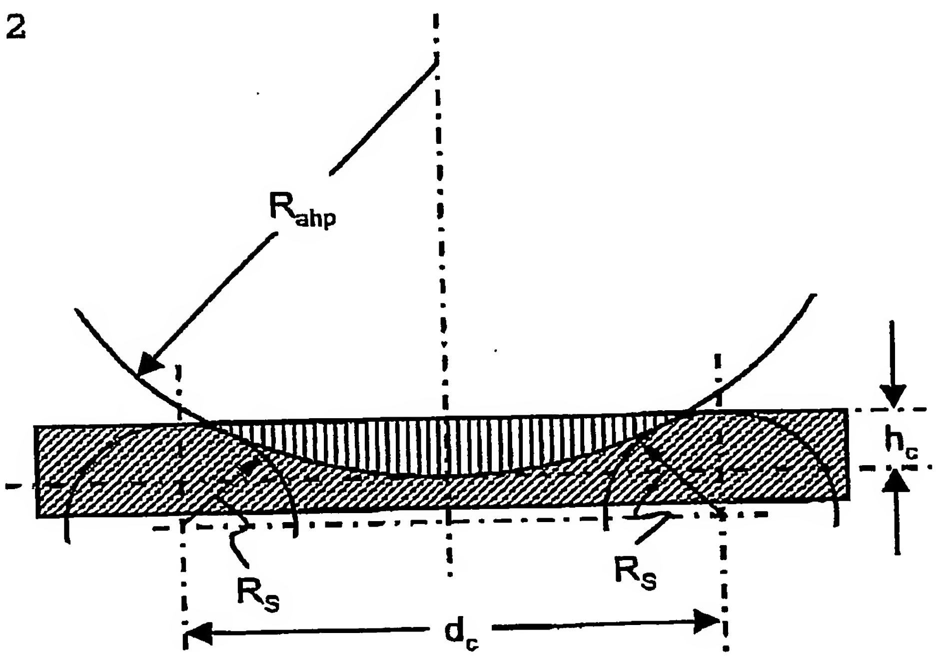


Fig. 3

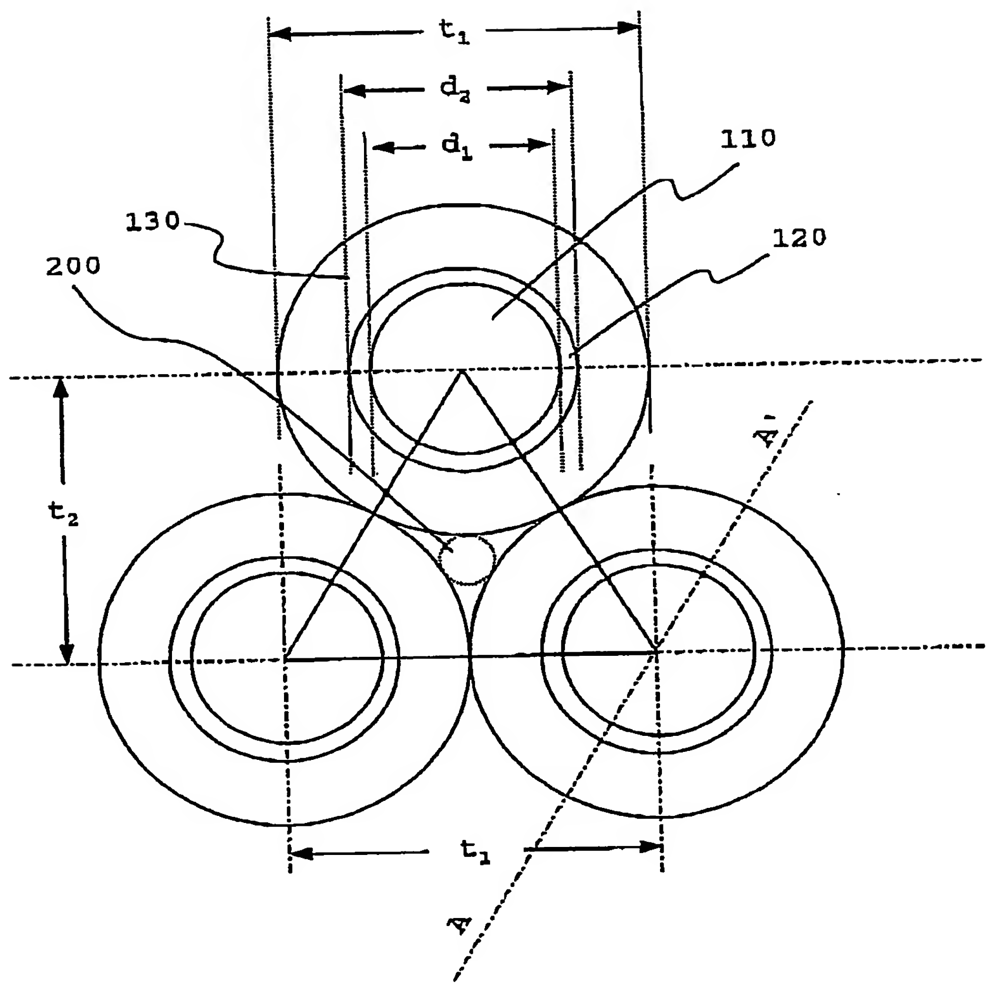


Fig. 4

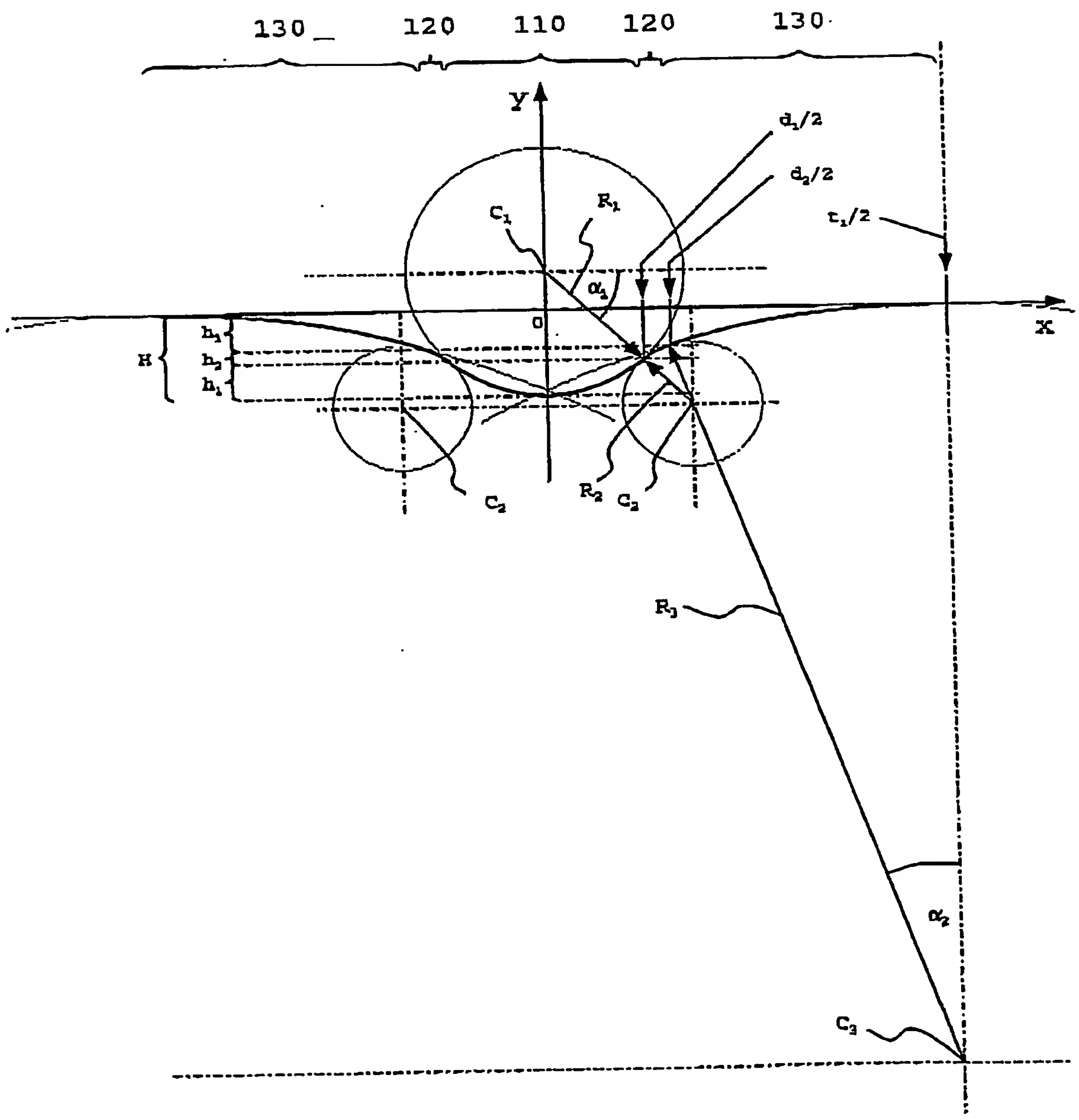

130
120
110
120
130
y
x
0
$d_1/2$
$d_2/2$
$t_1/2$
C_1
R_1
α_1
H
h_1
h_2
h_3
C_2
R_2
C_2
R_3
α_2
C_3

Fig. 5

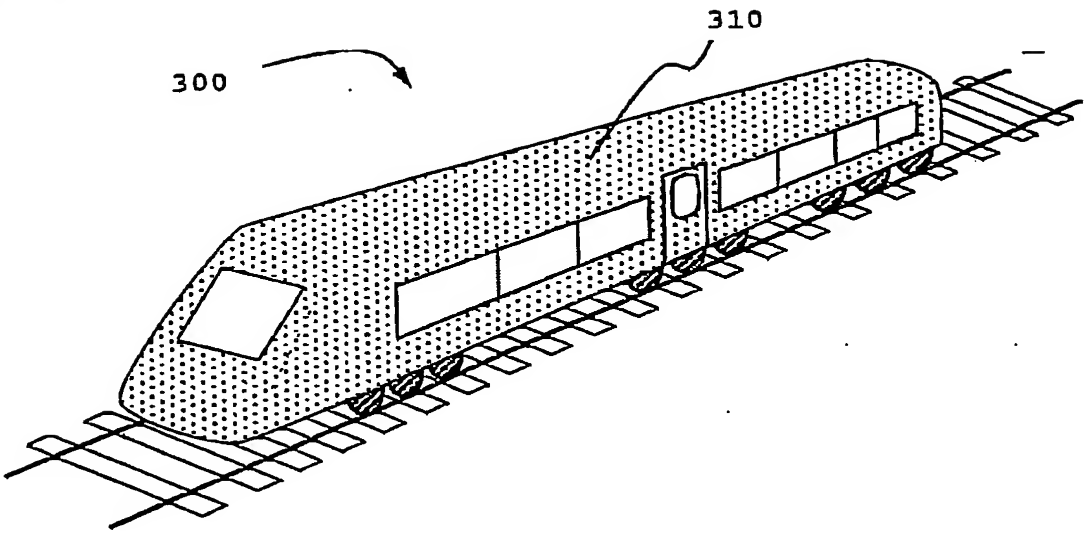


Fig. 6

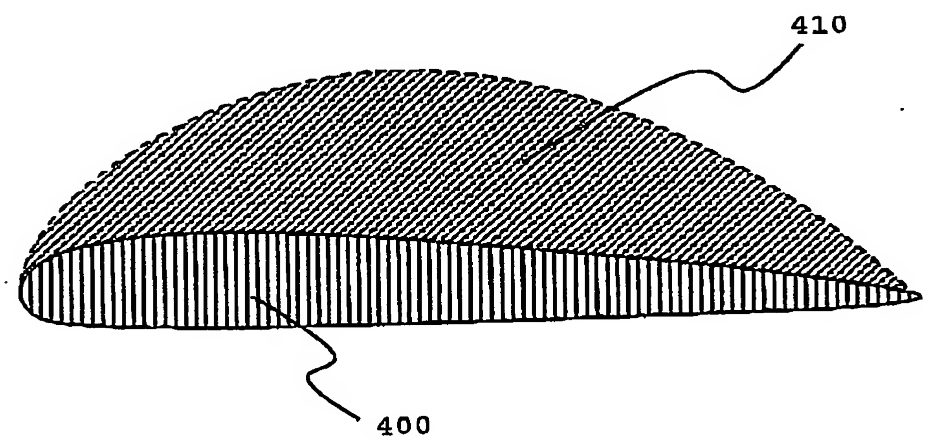


Fig. 7

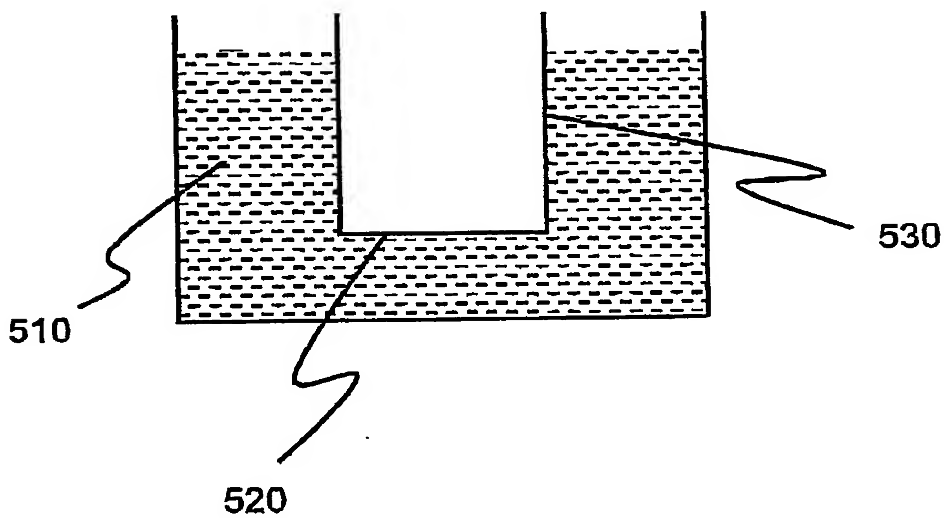


Fig. 8

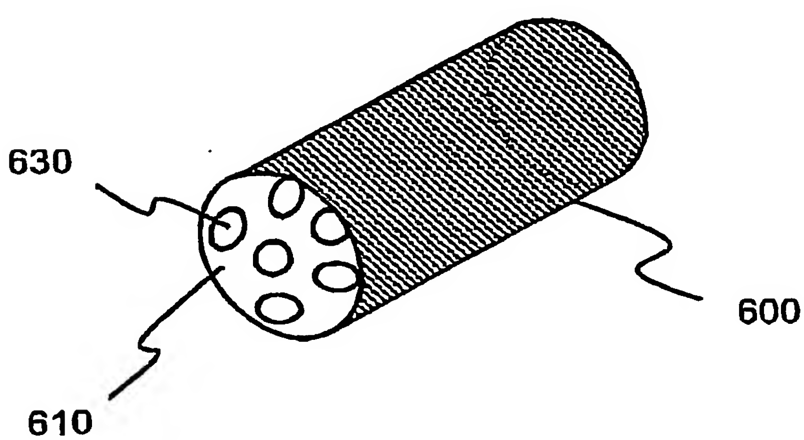


Fig. 10

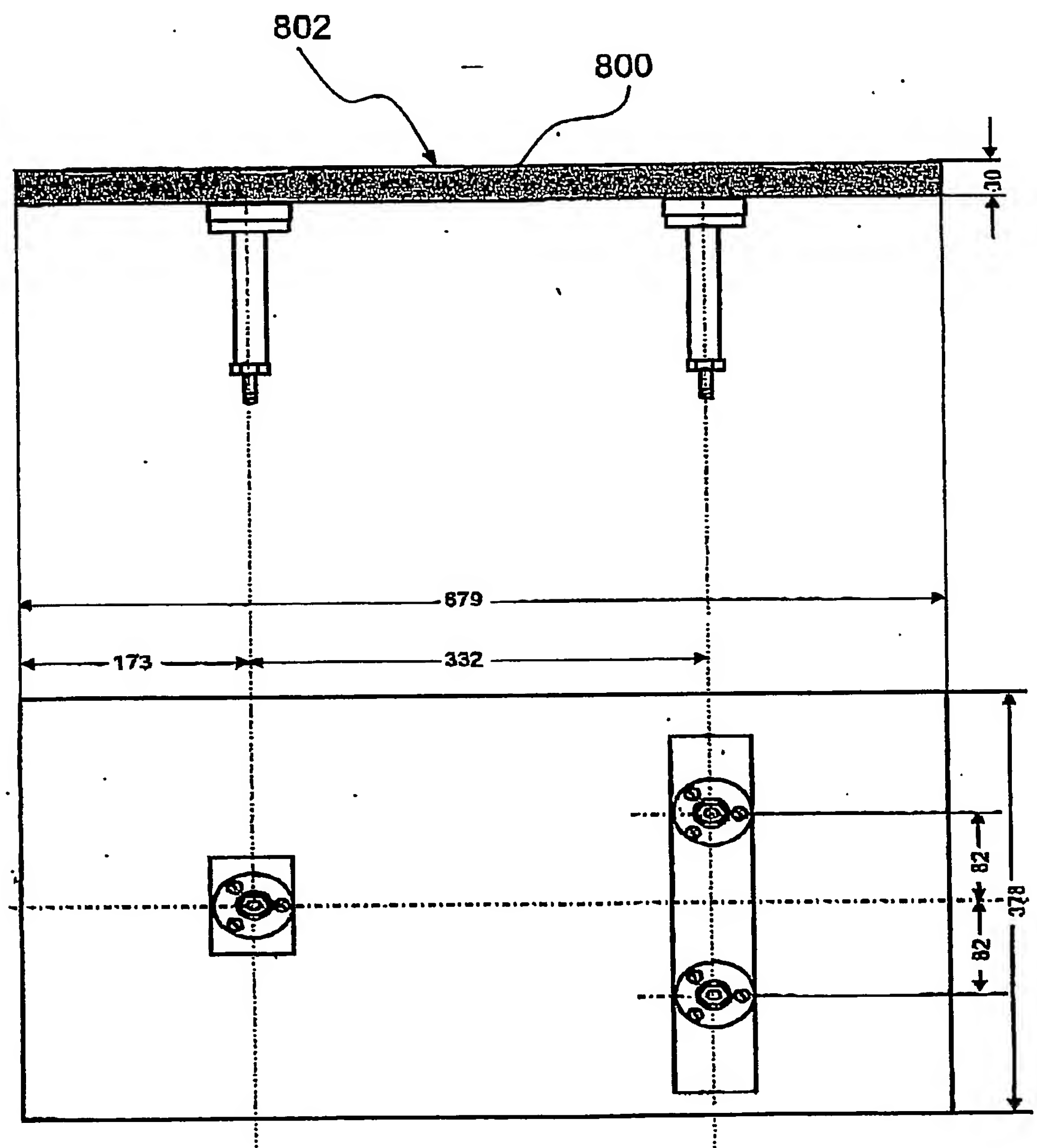


Fig. 11

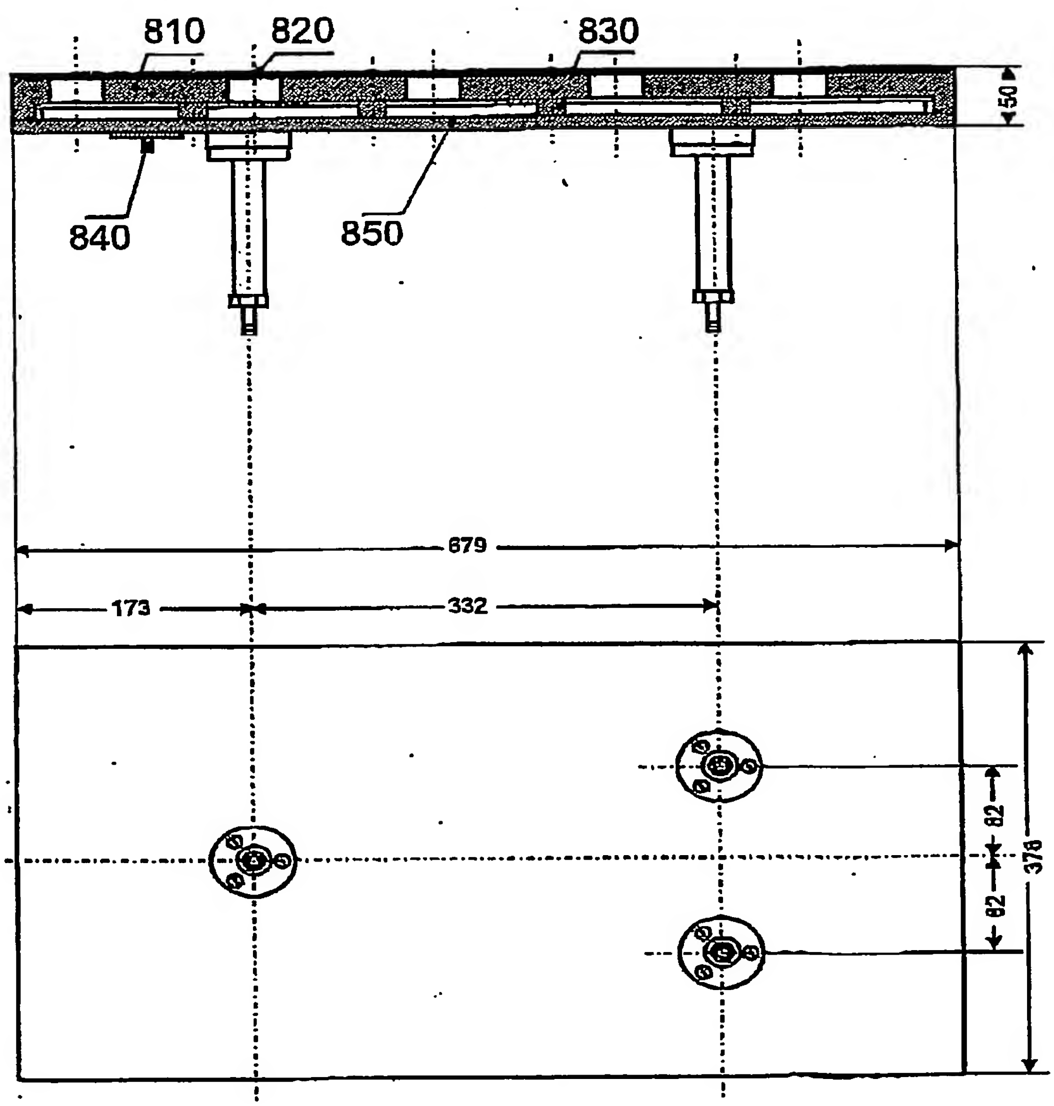
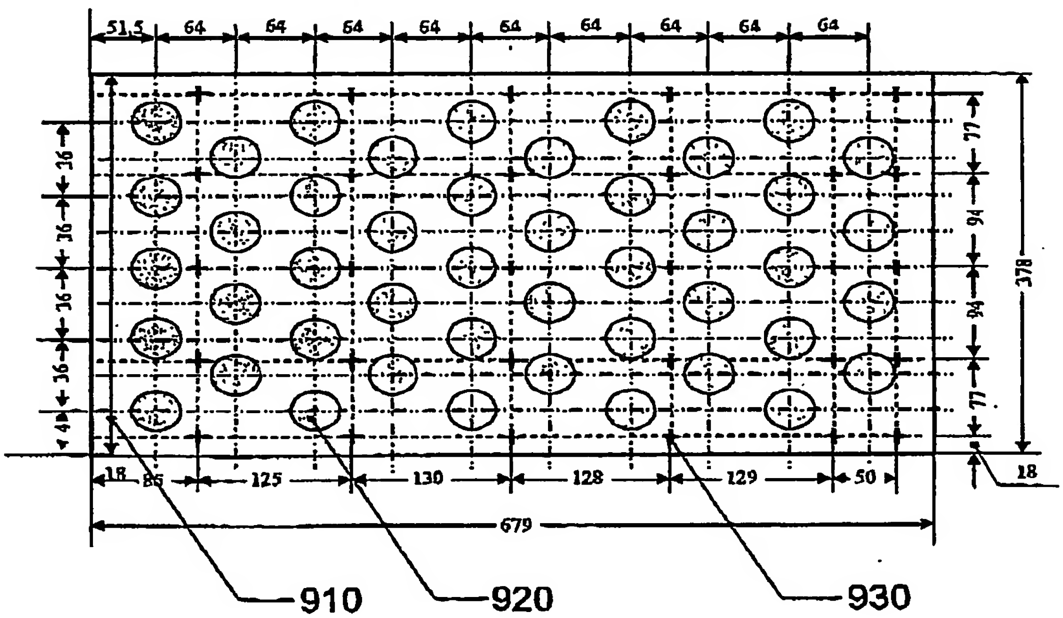


Fig. 12


51,5
64
64
64
64
64
64
64
64
64
36
36
36
36
40
77
94
94
77
378
18
85
125
130
128
129
50
18
679
910
920
930